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IMPLEMENTATION OF FUZZY LOGIC CONTROLLER BASED VOLTAGE EQUIVALIZER FOR PV POWER GENERATION UNDER PARTIAL SHADING

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Abstract — *Photovoltaic (PV) systems have been developed into mature technology that has been used in specialized applications. Partially shaded photovoltaic system result in reduction of power generation and produces multiple maximum power points (MMPP) in the characteristics. In this project, voltage equalizer is employed to solve this issue. voltage equalizer is designed by incorporating inductor, capacitor, diode and filters in DC- DC converter. This equalizer receives the unbalanced voltages from PV array and makes it balanced by Converter operation itself. Small amount of power generated is transferred from the un-shaded PV to shaded PV so that the entire PV array is operating at the same voltage. It is observed that voltage imbalance is slowly eliminated by this equalizer.*

Keywords- *Partial shaded photo voltaic system, Voltage equalizer, Fuzzy logic controller, MMPP, PV array*

I. INTRODUCTION

Renewable energy is the energy which comes from natural resources such as sunlight, wind, rain, tides and geothermal heat. These resources are renewable and can be naturally replenished. Therefore, for all practical purposes, these resources can be considered to be inexhaustible, unlike dwindling conventional fossil fuels the global energy crunch has provided a renewed impetus to the growth and development of Clean and Renewable Energy sources [1]. Clean Development Mechanisms (CDMs) are being adopted by organizations all across the globe. Apart from the rapidly decreasing reserves of fossil fuels in the world, another major factor working against fossil fuels is the pollution associated with their combustion. Contrastingly, renewable energy sources are known to be much cleaner and produce energy without the harmful effects of pollution unlike their conventional counterparts. A PV plant comprises of number of arrays. A PV array contains a number of PV modules that are connected in series and parallel .The power generated from the PV array is the combination of the power derived from each PV module. Further, there could be shadowing effects by clouds and bodies surrounding the plant. Frequently, the PV arrays get shadowed, wholly or partially, by the moving clouds, adjacent buildings and towers, trees, utility and telephone poles [2]. There could be manufacturing tolerances, non-uniformity of ambient temperature in proximity of each panel due to uneven solar irradiation and air circulation, dust and spot dirtiness (leaves, bird droppings) .When one of the PV modules is shaded or does not obtain enough solar irradiation, it dissipates the power generated by the other PV modules.

The PV equalizer is used to solve the problem of partial shading effect. Equalizer is designed by using incorporating capacitor inductor diode filter. Unbalanced voltage from PV array gets balanced by converter operation and maximum power point tracking is achieved by using fuzzy logic controller. Then overall the efficiency of the operation is increased. The output of the PV array is fed to the Equalizer to reduce the impact of partial shading effect. Then the voltage from the PV equalizer is increased by using DC-DC converter operation. According to the variation in the input voltage the output voltage is varied in order to get constant and maximum voltage the pulse width provided to the converter is varied. This can be achieved by using fuzzy logic controller. Then the output of the converter is fed to the load.

Modeling of PV module necessarily requires taking weather data (irradiance and temperature) as input variables. The output can be current, voltage, power or other. However, to trace the characteristics I (V) or P(V) needs these three variables. Any change in the entries immediately implies changes in outputs [13].In the paper [4] is used to analyze the problem faced by photovoltaic system due to changing climatic conditions. The characteristics I(V) and P(V) are varied for different temperature and irradiance. In the paper [10], [15] the author describes about the partial shading effect which is a major problem faced by photovoltaic system. Singe switch voltage equalizer is used to reduce this effect. The single switch topology can considerably simplify the circuit compared with conventional equalizers requiring multiple switches in proportion to the number to PV modules/substrings. The various maximum power point tracking algorithm was studied from the papers [3]-[7]. Due to climatic condition the maximum power extracted from the PV cell is varied. Numerous MPP is achieved. Therefore Maximum power point tracking algorithm is essential to track global MPP from each panel. Due to the variation of the maximum power point (MPP) of photovoltaic (PV) generators with solar radiation and temperature, boost dc–dc converters placed between PV modules and inverters in grid-connected PV systems have to be controlled in a variable operating-point condition[3],[5].

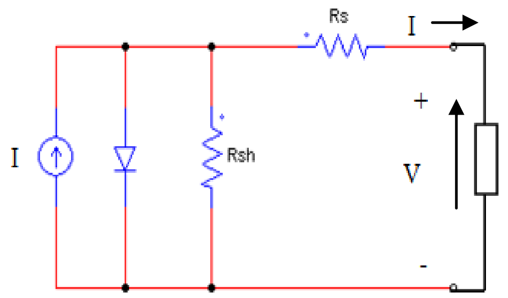

Fig. 1Single diode model of a PV cell

In the figure 1 we consider a current source (I) along with a diode and series resistance (R_s). The shunt resistance (R_{sh}) in parallel is very high, has a negligible effect and can be neglected.

The output current from the photovoltaic array is

$$I=I_{sc} - I_d \quad (1)$$

$$I_d= I_o (e^{qV_d}/kT - 1) \quad (2)$$

where

I_o is the reverse saturation current of the diode,
q is the electron charge,
V_d is the voltage across the diode,
k is Boltzmann constant (1.38 * 10-19 J/K) and
T is the junction temperature in Kelvin (K)

From eq. 1 and 2

$$I = I_{sc} - I_o (e^{qV_d}/kT - 1) \quad (3)$$

Using suitable approximations,

$$I = I_{sc} - I_o (e^{q((V+IRs)}/nkT) - 1) \quad (4)$$

where,

I is the photovoltaic cell current,
V is the PV cell voltage,
T is the temperature (in Kelvin),
n is the diode ideality factor.

In order to model the solar panel accurately we can use two diode model but in our project our scope of study is limited to the single diode model. Also, the shunt resistance is very high and can be neglected during the course of our study.

1.1VOLTAGE EQUALIZER

Input of the equalizer circuit is obtained from the output of the PV string voltage. The multi output of this circuit is connected across each PV panel. The advantage of this circuit includes the usage of single switch, simple, easy and control.

MODE 1(T_{ON}):

The switch is in ON position the output of series connected PV panels supply the power to the voltage equalization circuit .during this period ,currents of all inductors in equalization circuit increases and inductors store the corresponding energies. The current flowing through L_{IN} and C_{IN} also flows towards the switch.

MODE 2 (T_{OFF}):

The switch (Q) is OFF. During this period, the diode corresponding to lowest voltage PV panel will get forward biased. Hence stored energies in the inductor transferred to the module.

MODE 3 (T_{OFF}):

The switch and diodes are in off position .during this period, inductor currents are constant and equal to zero and therefore the inductor voltage must be zero. After the diode current falls to zero, the currents in the equalizer inductor becomes constant equal to zero. Therefore average current of diode equal to average current of inductors respectively ; only ripple current will flow through these inductors. as the large power generated by un shaded panels is transferred to the low illuminated panel through the equalizing circuit slowly imbalance of PV panel voltage vanishes.

1.2 BOOST CONVERTER

As stated in the introduction, the maximum power point tracking is basically a load matching problem. In order to change the input resistance of the panel to match the load resistance (by varying the duty cycle), a DC to DC converter is required. figure 2 shows the circuit diagram of boost converter.

It has been studied that the efficiency of the DC to DC converter is maximum for a buck converter, then for a buck-boost converter and minimum for a boost converter but as we intend to use our system either for tying to a grid or for a water pumping system which requires 230 V at the output end, so we use a boost converter.

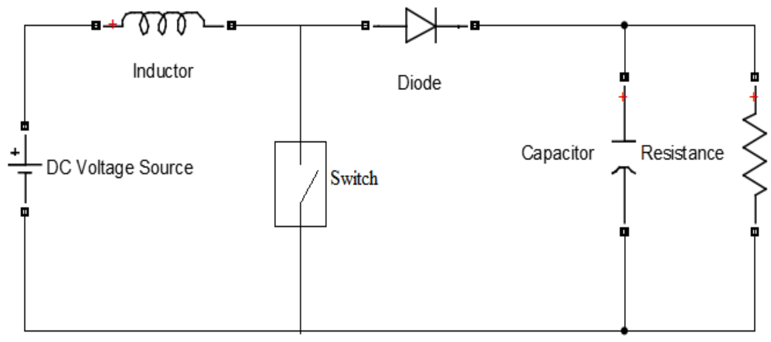

Figure 2 Circuit diagram of a boost converter

1.2.1 MODE 1 OPERATION OF THE BOOST CONVERTER

When the switch is closed the inductor gets charged through the battery and stores the energy. In this mode inductor current rises (exponentially) but for simplicity we assume that the charging and the discharging of the inductor are linear. The diode blocks the current flowing and so the load current remains constant which is being supplied due to the discharging of the capacitor. The mode 1 operation is explained in the figure 3

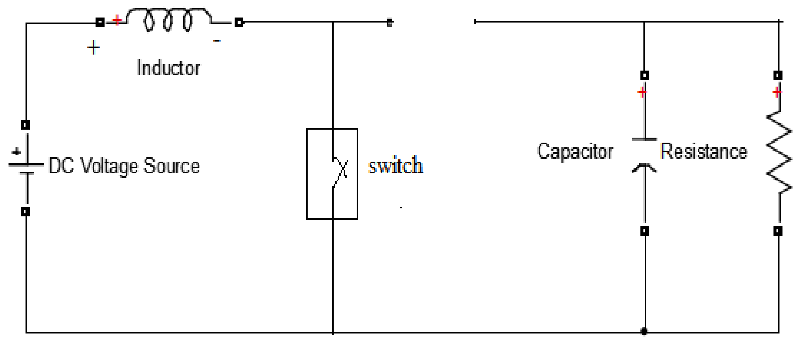

Figure 3 Mode 1 operation of boost converter

1.2.2 MODE 2 OPERATION OF THE BOOST CONVERTER

In mode 2 the switch is open and so the diode becomes short circuited. The energy stored in the inductor gets discharged through opposite polarities which charge the capacitor. The load current remains constant throughout the operation. The mode 2 operation is explained in the figure 4

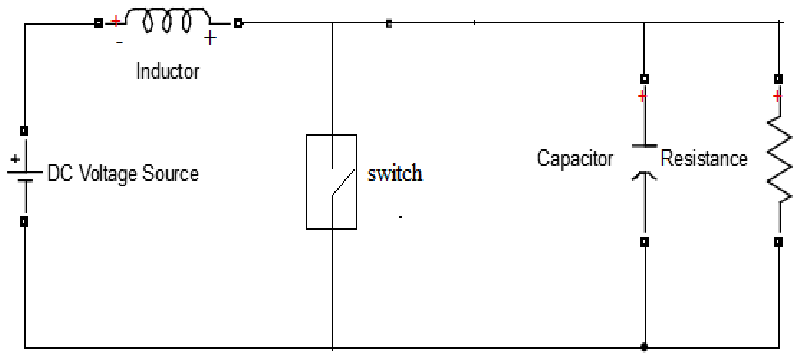

Figure 4 Mode 2 operation of boost converter

II PROPOSED SCHEME

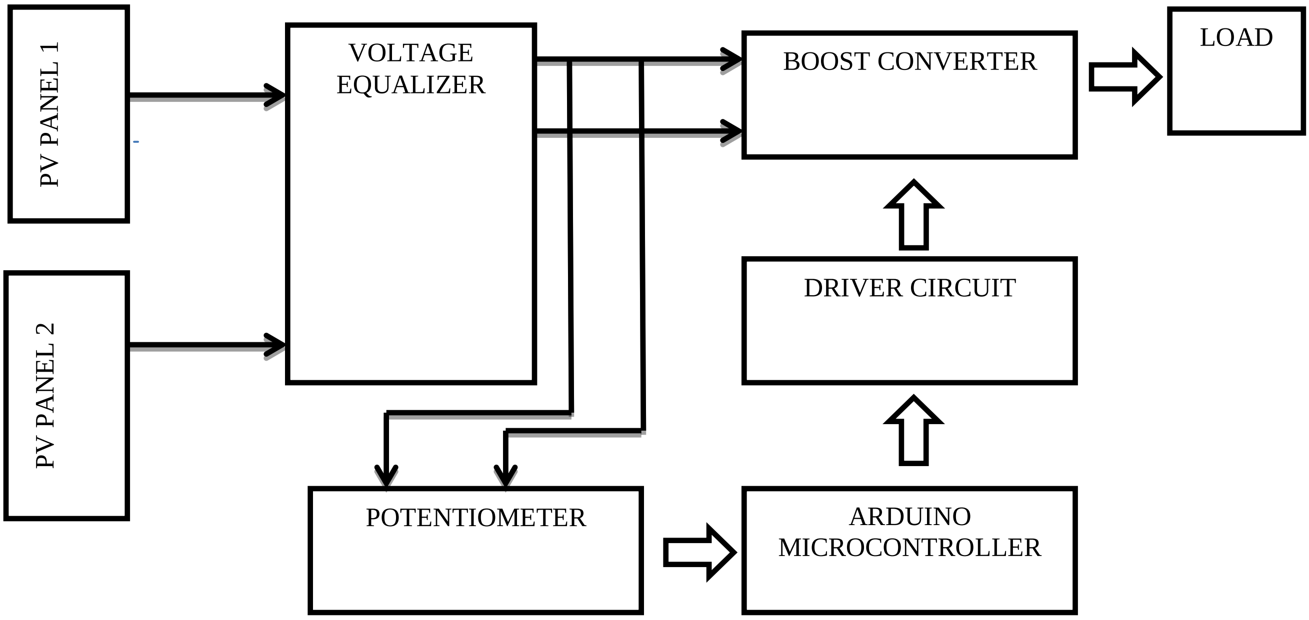

Figure 5 Block diagram of the proposed scheme

The figure.5 explains the hardware implementation of the project. The outputs of the two PV panels are fed to the voltage equalizer to get constant voltage from the panels. Then the voltage is boost up using DC-DC converter. The PWM Pulse which is generated from the Arduino microcontroller is fed to the boost converter to vary the duty cycle. In order to isolate the ground connection between the driver circuit and power circuit. The voltage signal from the panels is converted into PWM signal by using microcontroller. The input voltage provided to the converter was varied but the output voltage remains constant by adjusting the duty cycle of PWM signal according to the variation in the input signal.

III HARDWARE IMPLEMENTATION

SOLAR PANEL:

Solar panels absorb the sunlight as a source of energy to generate electricity or heat. A Photovoltaic module is a packaged connect assembly of typically 6 x10 photovoltaic solar cells. In this project, two solar panels are used to check out variation in the partial shading. The solar panel image was shown in the figure 6.

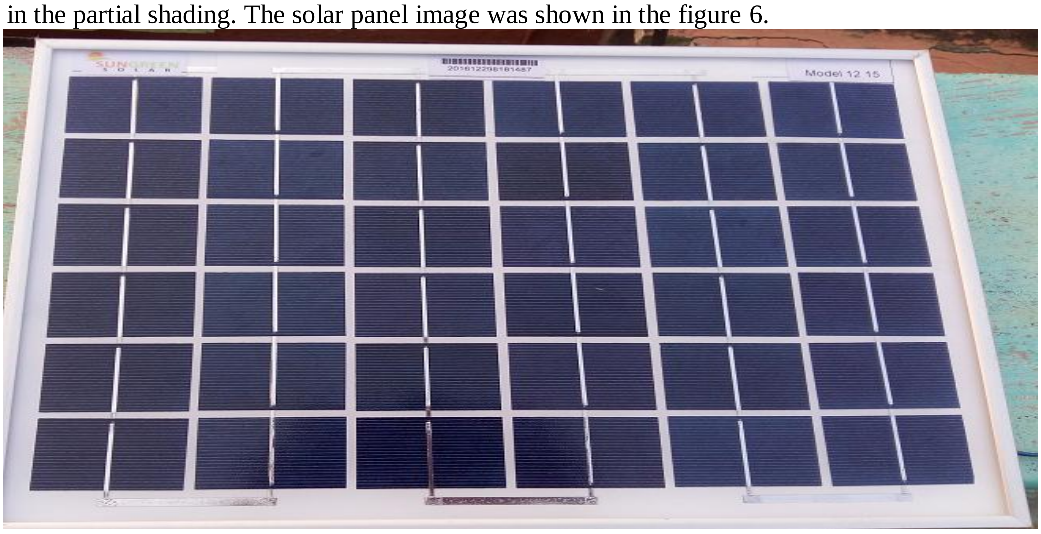

Figure 6 solar panel

A 12V panel is not really a 12V panel at all. It's really a somewhere in between 12 V and 21V panel depending on what load is connected to it and how bright the sunlight is. The panel has an internal resistance which changes dynamically with differing irradiance. For eg: 40 W,18V at .62 A, the panel delivers 40 W only if the resistance is 3.24 Ω. Otherwise the power is less than 40 Watts. Load resistance is higher or lower than panel internal resistance at MMP, the power drawn from the panel will be less than max available.

Solar panel specification:

The following table shows the solar panel specification of 10 Watts.

Table 1: solar panel specification

PARAMETERS	SPECIFICATIONS
Rated maximum power	10W
Open circuit voltage	21.60 V
Short circuit current	.78 A
Voltage at maximum power	17.54 V
Current at maximum power	.62 A
Maximum system Voltage	600 VDC
Operating temperature	-40 to 85 C
Reverse current leakage	<10µA
Dimensions	310 x 368 x 18 mm
Weight	1.5 Kg
Regulation Voltage	14.1 V
Accuracy	60 mV

3.4. VOLTAGE EQUALIZER:

The figure 7 shows the Hardware implementation of voltage equalizer with Capacitor inductor diode Filter. Diode is used to prevent the reverse flow of current from load to source. Inductor and capacitor are the energy storing elements used to store the energy and to maintain equal voltage level without any variation in the voltage provided to the load.

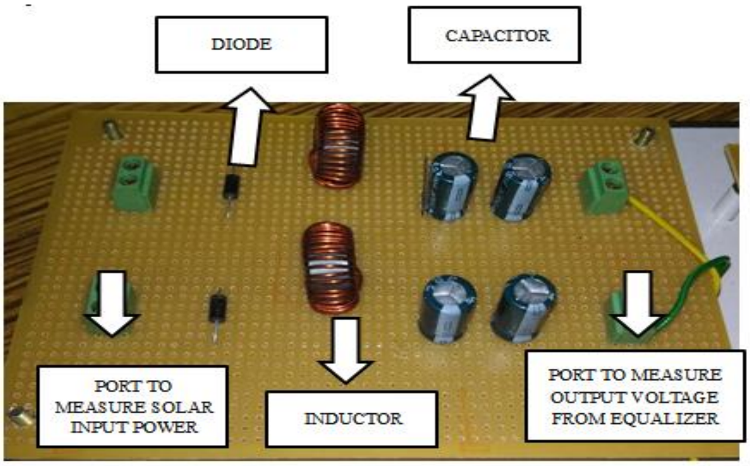

Figure 7 Hardware implementation of voltage equalizer

3.5 BOOST CONVERTER:

Input capacitor is filtered out the ripples. Similarly output capacitance is required to minimize the voltage overshoot and ripple present at the output of a buck converter. Large overshoots are caused by insufficient output capacitance and large voltage ripple is caused by insufficient capacitance as well as a high equivalent – series resistance (ESR) in the output capacitor. To meet the ripple specification in the boost converter circuit capacitor with low ESR is essential.

IV RESULTS AND DISCUSSION

The figure 8 shows that the overall hardware implementation of the scheme. The voltage equalizer is used to reduce the impact of partial shading effect in the solar output. The voltage provided to the load has to be maintained constant by using Boost converter. Driver circuit is used to provide isolation between the power circuit and control circuit.PWM pulse is generated by using Arduino and it is fed to the boost converter switch.

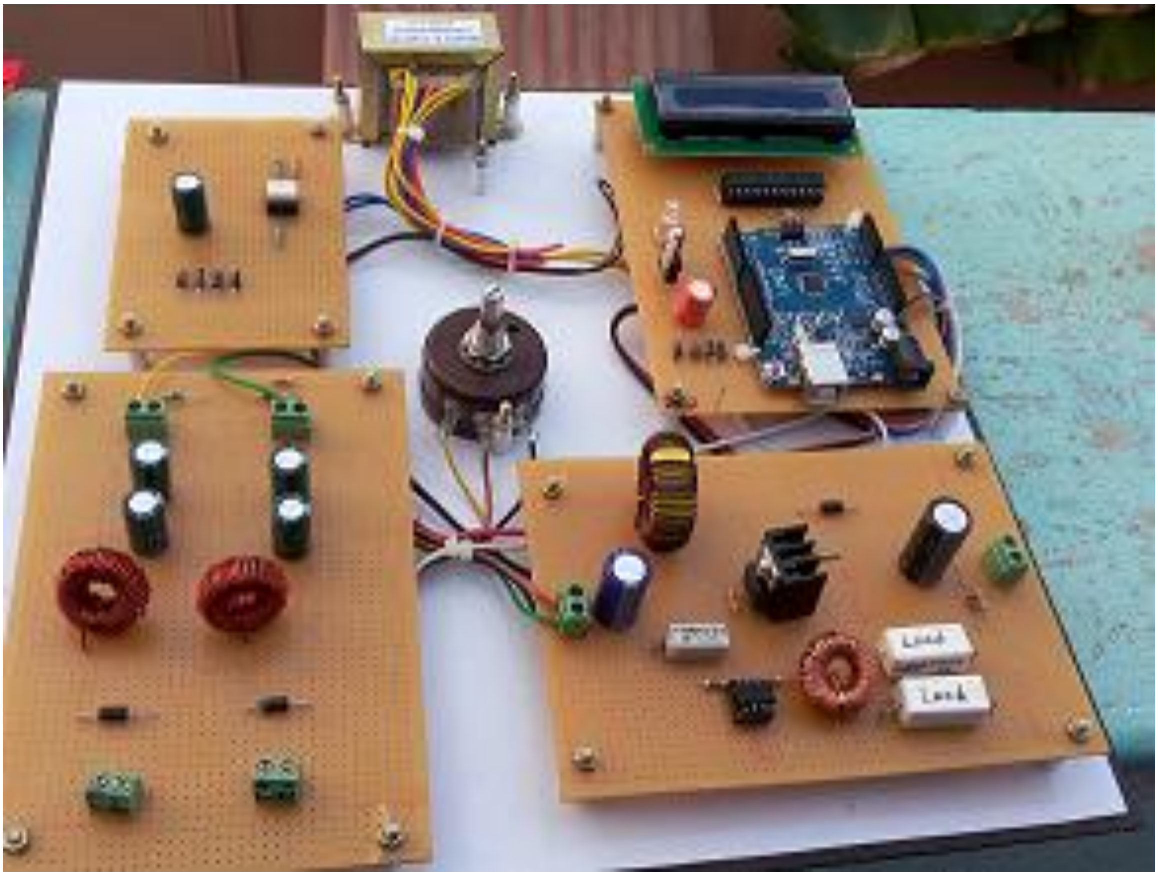

Figure 8 Hardware of the scheme

The figure 9 shows that the output voltage waveform of the solar panel without voltage equalizer.

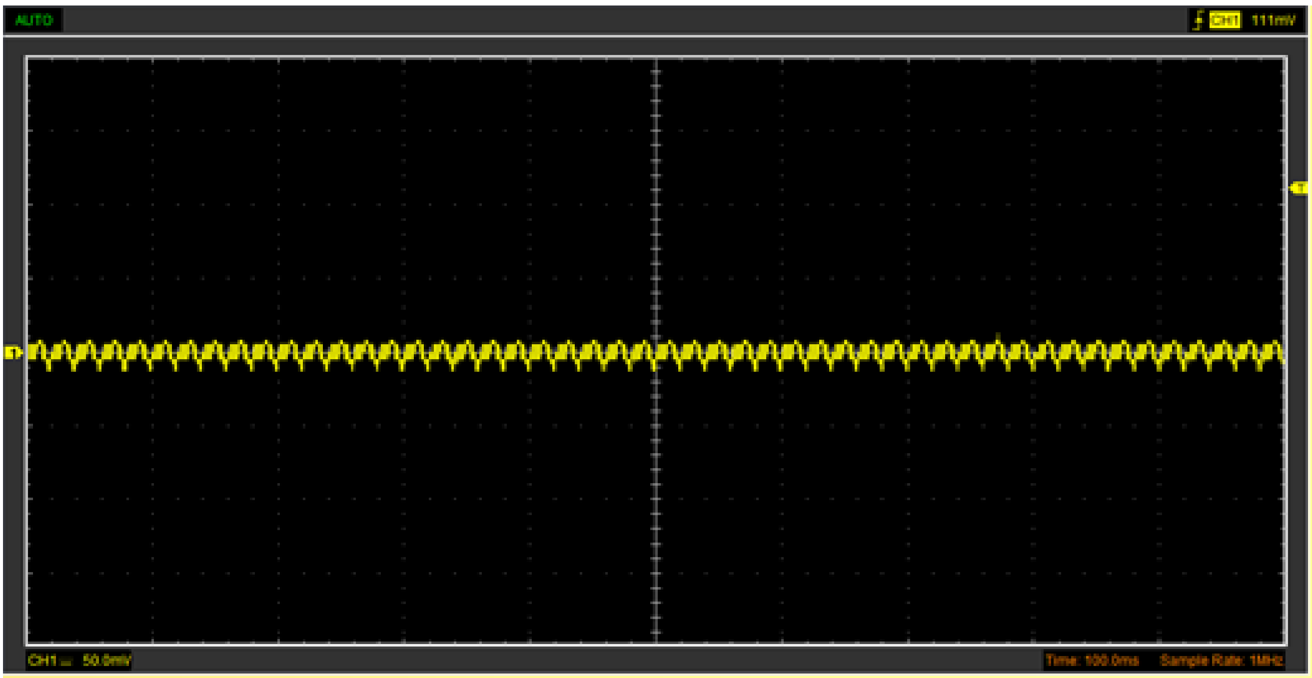

Figure 9 panel output voltage

The figure 10 shows that the voltage waveform of the panel after passing capacitor inductor diode filter. There is no variation in the output voltage, it remains constant even though variation in the input signal .i.e. voltage output from the solar panel.

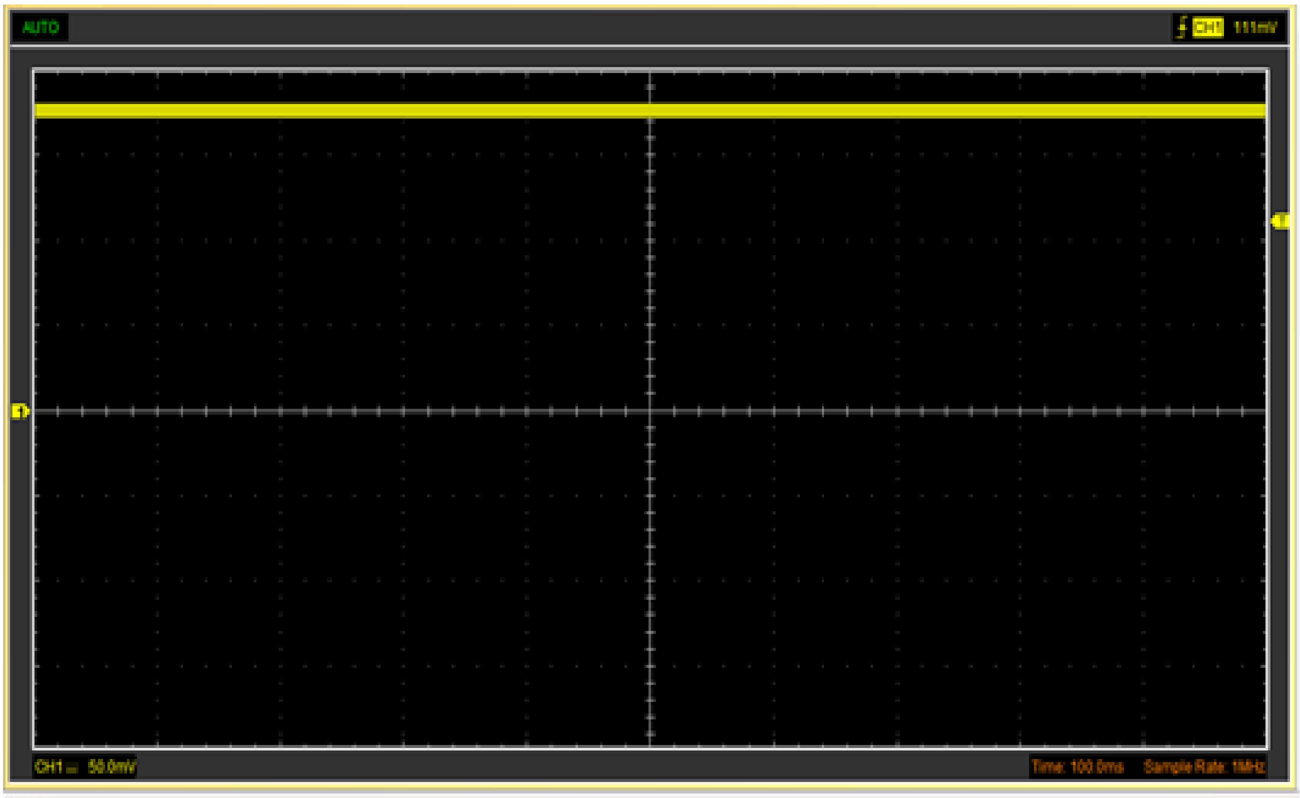

Figure 10 voltage Equalizer output

The figure 11 shows that the PWM pulse signal of MOSFET switch. The duty cycle of PWM signal is adjusted depends upon the variation in the input signal fed to the converter. To maintain output voltage fed to the load constant, pulse width has been varied according to the variation in the input signal.

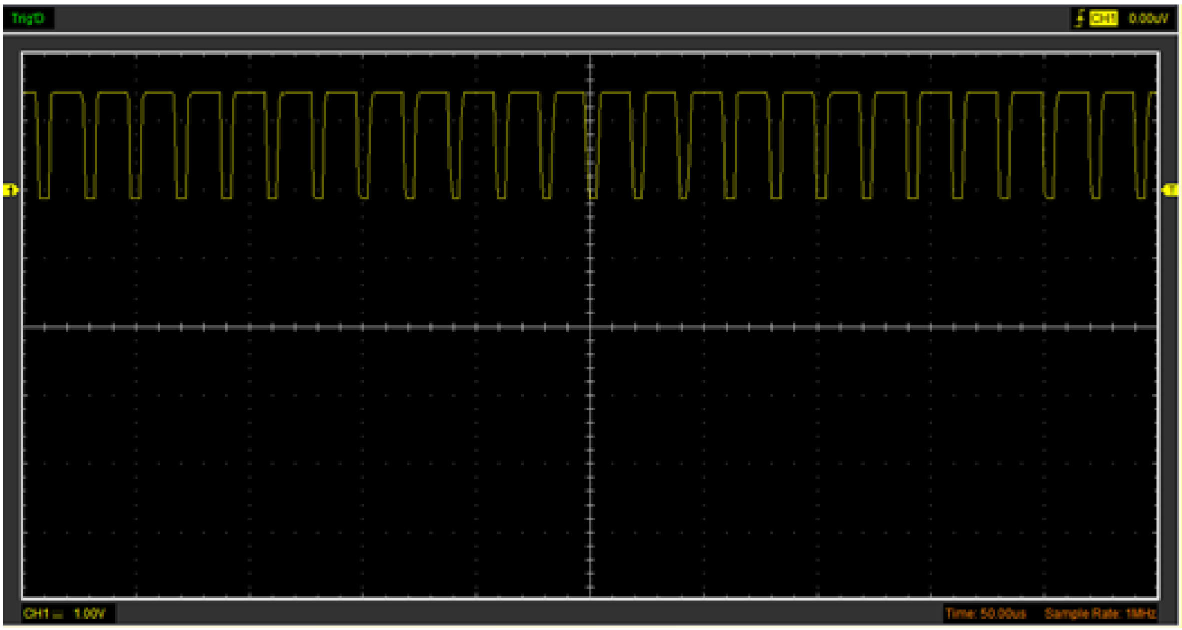

Figure 11 PWM pulse signal

The figure 12 shows that the output voltage waveform which is fed to the input signal. The amplitude of the output signal is 24 V .The input voltage fed to the load has not been varied. If the input signal fed to the load was varied frequently means there is a possibility for getting damaged.

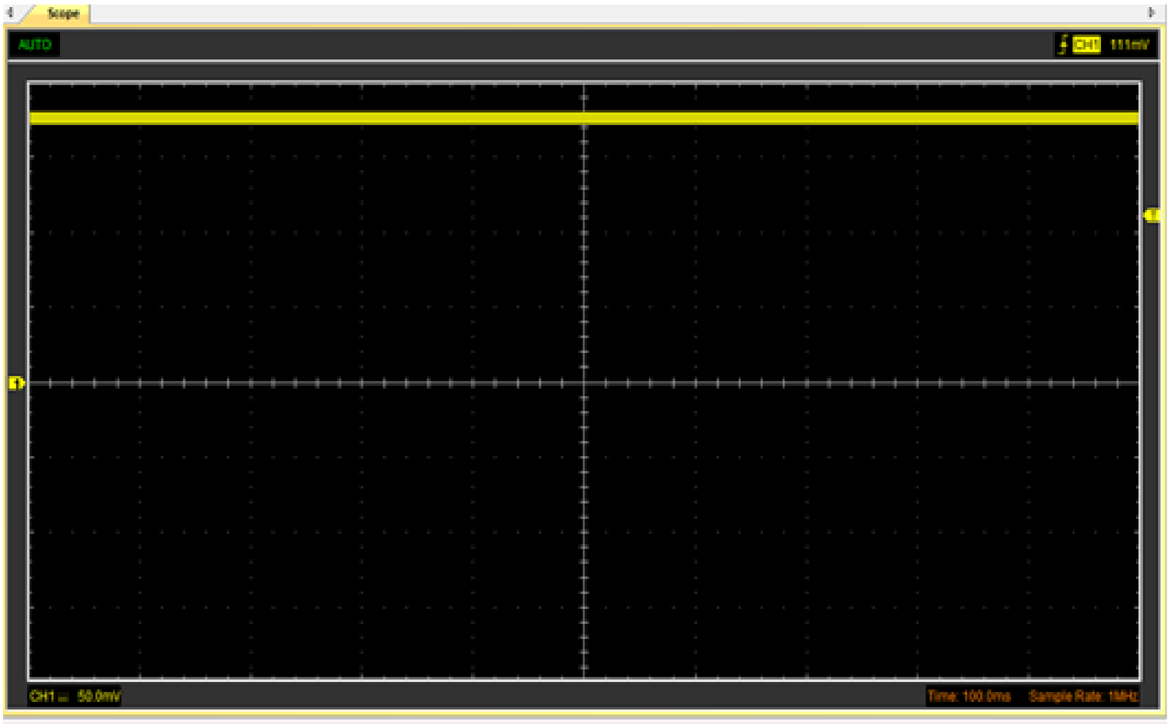

Figure 12 output load voltage

V. CONCLUSION

The voltage equalizer circuit has been modeled to reduce the impact of partial shading problem in solar panels. The boost converter circuit was designed to track the maximum power. Thus the output voltage of panel to the load was maintained constant. Thus the load receives constant voltage without any variation even though there is a variation in the solar panels output. The voltage equalizer plays a major role in providing constant voltage to the DC-DC converter.

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